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A COMPUTER PROGRAM FOR BACKSCATTER
BY TARGETS COMPOSED OF CONES,
CYLINDERS, AND DISKS - 2430-5

C.E. Ryan, Jr.

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April 1968

DEPUTY FOR SURVEILLANCE AND CONTROL SYSTEMS
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
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(Prepared for Contract No. AF 19(628)-67-C-0308 by The Ohio State
University, ElectroScience Laboratory, Department of Electrical
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FOREWORD

This report, OSURF report number 2430-5, was prepared by The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering, 1320 Kinnear Road, Columbus, Ohio. Research was conducted under Contract F 19628-67-C-0308. Lt. Nyman was the Electronic Systems Division Program Monitor for this research.

This technical report has been reviewed and is approved.

BERNARD J. FILLIATREAU
Contracting Officer
Space Defense & Command Systems Program Office

ABSTRACT

This report describes a computer program for determining the backscattered fields of a conducting body of revolution composed of sections of cones and cylinders. The target may be closed at one or both ends with circular disks. The target may have as many as 20 sections, and the program can readily be modified to handle a larger number. The backscattered field for E_θ or E_ϕ polarization is computed using wedge diffraction theory and geometrical optics. The computed results are in good agreement with experimental measurements for cones, cylinders, double cones, and conically capped cylinders.

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A COMPUTER PROGRAM FOR BACKSCATTER BY TARGETS COMPOSED OF CONES, CYLINDERS, AND DISKS

INTRODUCTION

A computer program, which computes the backscattered field of a body of revolution composed of cones, frustums, cylinders, and disks is given in Appendix I. This program is coded in Fortran IV and the cards are numbered consecutively in columns 76-80. This program has been tested for cones, cylinders, frustums, conically capped cylinders, and double cones, for E_θ polarization of the incident and scattered fields. The results of these tests are presented in Reference 1. The theoretical basis for this program is described in References 1 and 2.

The function of this program is to compute the backscattered field as a function of aspect angle and/or frequency for a given target. This is accomplished by reading and storing the target description, identifying the regions of aspect angle corresponding to axial and specular directions, and applying the appropriate geometrical theory of diffraction solutions to calculate the scattered fields.^{1, 2} In the form presented here the angular pattern for a given target and frequency is computed. Modification of the program to compute a frequency curve for a given target and aspect angle is straightforward.

TARGET DESCRIPTION

The target shape is described in cylindrical coordinates by the second degree equation

$$(1) \quad F(\rho, z) = A_1 \rho^2 + A_2 z^2 + A_3 \rho z + A_4 z + A_5 \rho + A_6 = 0 \quad .$$

As this program is written to handle only targets composed of cones, frustums, cylinders and disks, the description of the profile of the target is that of a straight line segment, and may be expressed as

$$(2) \quad F(\rho, z) = A_4 z + A_5 \rho + A_6 = 0$$

where $A_1 = A_2 = A_3 = 0$. In addition to Eq. (2) the boundaries of each section of the target must be specified. That is, within each section of

the target the profile is specified by a set of constants A_4 , A_5 , A_6 . The next section is described by a new set of constants and so forth. As an example consider the target shown in Fig. 2. This target is composed of a cone, a cylinder, and a disk, and is a three section target. Thus a set of constants must be specified for each section and the angular boundaries of the sections specified. Figure 1 gives the relations by which the constants may be determined for each surface. The computer format for this input data will be discussed below.

If Eq. (1) is used to describe the target, i.e., any of the constants A_1 , A_2 , A_3 non-zero, this program will compute the scattered field due to the wedge type discontinuities on the target but will not calculate the correct total scattered field. This is because there is no provision in this program to calculate the geometrical optics field of a doubly curved surface. A calculation of this geometrical optics field is included in the creeping wave computer program.³

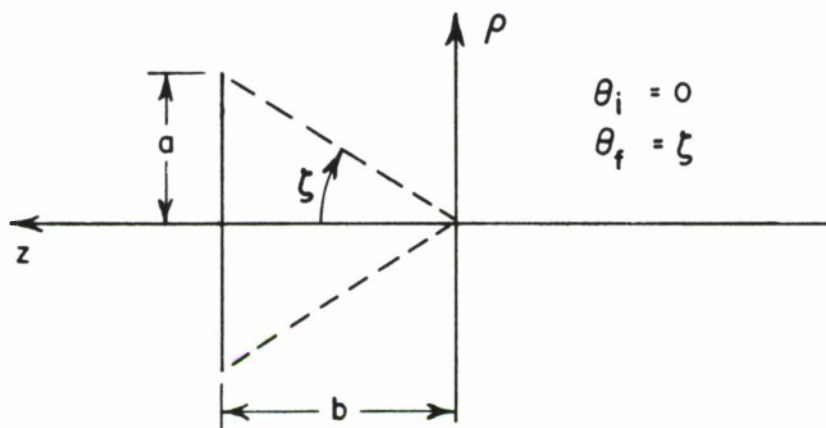
WEDGE DIFFRACTION COMPUTER PROGRAM

Referring to the computer program listing shown in Appendix I, the function of the significant sections of the program will be discussed. The card numbers associated with each section will be specified. This discussion, together with the comment cards included in the program listing, is intended to give sufficient information about the program to enable a qualified programmer to both use and modify the program. Statements which are in common use in Fortran IV such as DIMENSION, COMPLEX, and FORMAT statements will not be discussed as it is assumed that the reader has a knowledge of Fortran IV.

The COMMON declaration (0006) is used to store the constants required in Eq. (2) in the common block labelled /DATA/. This common block is used in conjunction with the unlabelled common block to transfer a particular set of constants $A_1(I)$ to $A_6(I)$ into the unlabelled common regions shared by the subroutines. This provision reduces the number of calling variables required by each subroutine.

The READ (0030-0040) statements in this block of statements read the required data and provision is also made to write out this data for the purpose of identification.

The statements 0041-0045 initialize constants which are required in the calculations.

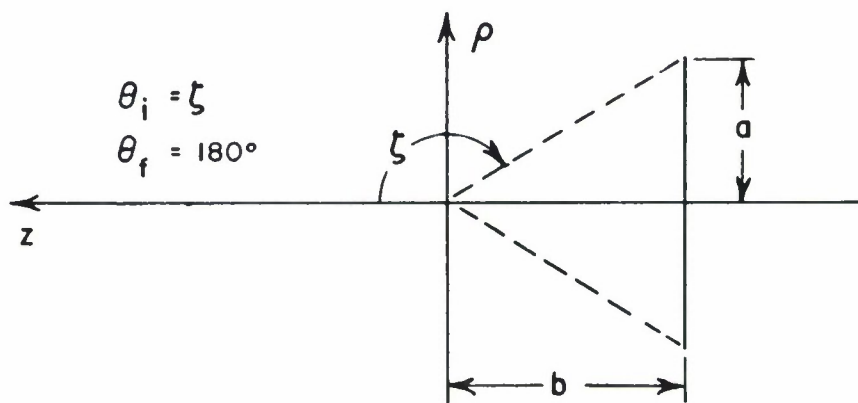


$$\zeta = \text{TAN}^{-1} \left(\frac{a}{b} \right)$$

$$A_4 = 1$$

$$A_5 = 0$$

$$A_6 = -b$$



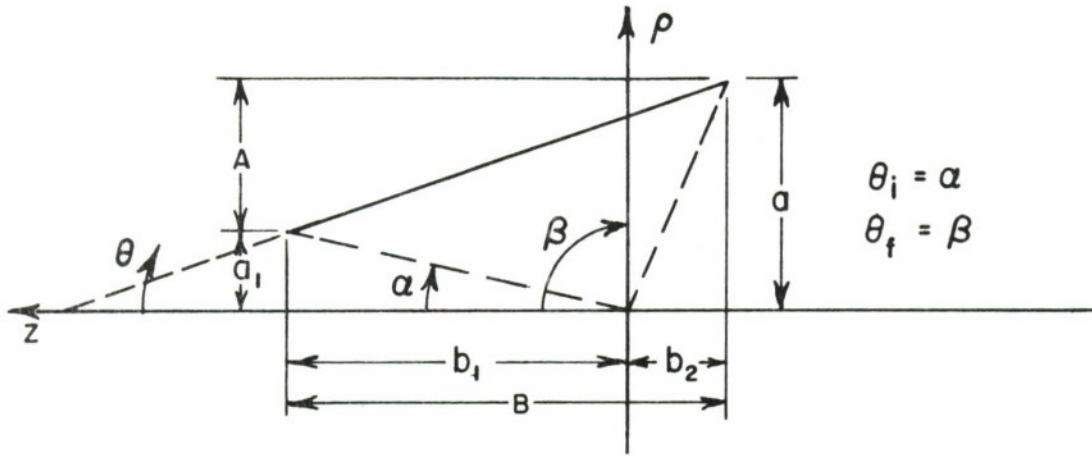
$$\zeta = 180^\circ - \text{TAN}^{-1} \left(\frac{a}{b} \right)$$

$$A_4 = -1$$

$$A_5 = 0$$

$$A_6 = -b$$

Fig. 1(a). Straight line segments and their corresponding analytic description.

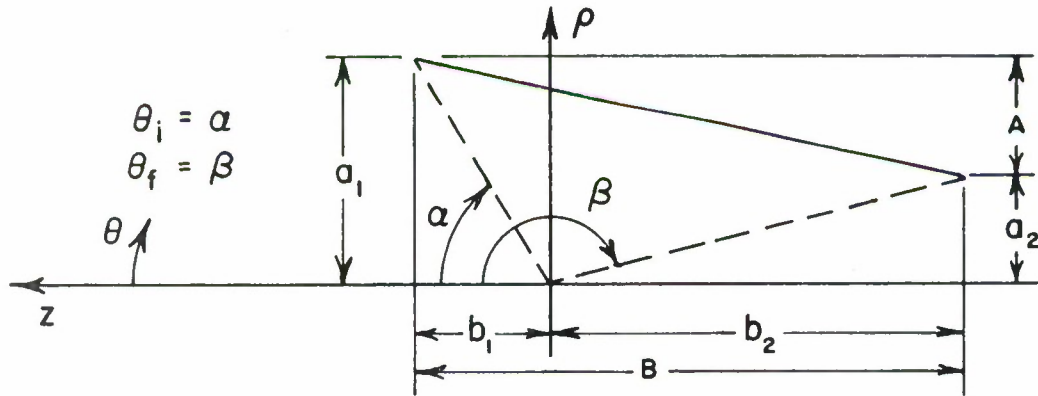


$$\alpha = \text{TAN}^{-1} \left(\frac{a_1}{b_1} \right) \quad \beta = 180^\circ - \text{TAN}^{-1} \left(\frac{a_2}{b_2} \right)$$

$$A_4 = \frac{A}{B}$$

$$A_5 = 1$$

$$A_6 = - \left[b \left(\frac{A}{B} \right) + a_1 \right]$$



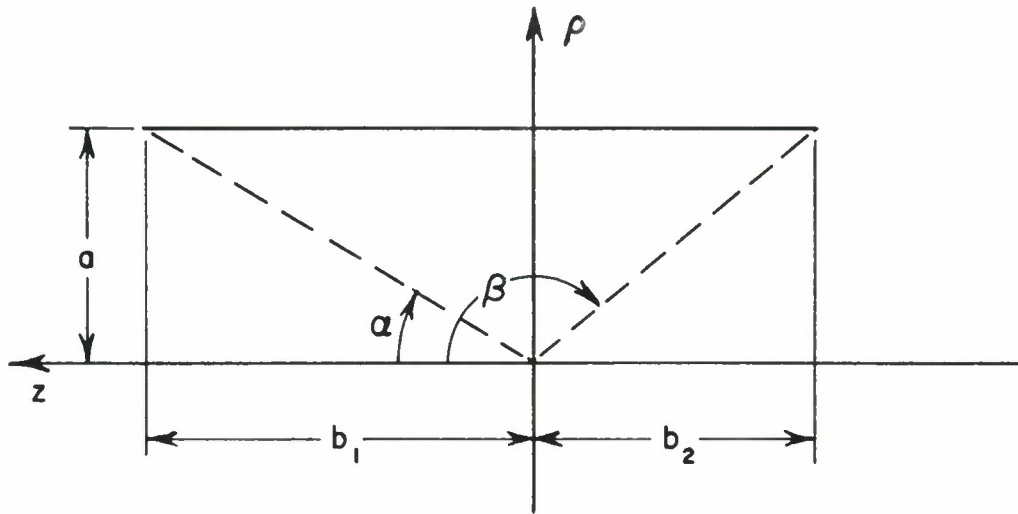
$$\alpha = \text{TAN}^{-1} \left(\frac{a_1}{b_1} \right) \quad \beta = 180^\circ - \text{TAN}^{-1} \left(\frac{a_2}{b_2} \right)$$

$$A_4 = -\frac{A}{B}$$

$$A_5 = 1$$

$$A_6 = - \left[b_2 \left(\frac{A}{B} \right) + a_2 \right]$$

Fig. 1(b). Straight line segments and their corresponding analytic description.



$$\begin{aligned}
 \theta_i &= \alpha & \theta_f &= \beta \\
 \alpha &= \text{TAN}^{-1} \left(\frac{a}{b_1} \right) & \beta &= 180^\circ - \text{TAN}^{-1} \left(\frac{a}{b_2} \right) \\
 A_4 &= 0 \\
 A_5 &= 1 \\
 A_6 &= -a
 \end{aligned}$$

Fig. 1(c). Straight line segments and their corresponding analytic description.

The next block of statements (0046 - 0108) identifies the geometrical properties of the target. The function of this section may be described by consideration of a particular target. Figure 2 shows a particular target composed of a cone-cylinder-disk. The geometrical properties of interest are the locations of the wedges, the wedge angles $WA(IW)$, the specular directions $THSX(IW)$, and the length of the specular line $FLSX(IW)$. This task is accomplished by examining the normal vectors (VNX, VNY, VNZ) of the adjoining surfaces at the junction between two sections. The wedge angle is then obtained from the scalar product of the normal vectors, the specular direction is determined by checking for parallel normals at the ends of each section, and the length of the specular line is obtained using the law of cosines.

The next block of statements (0109 - 0110) remove the redundancy in specular angle which can occur when the z-axis is a specular direction. For example, in the case of a closed cylinder the directions $\theta = 0^\circ, 180^\circ$ are specular directions. In a subsequent test for a specular region in (0190 - 0196) the sine of the specular angle is taken. As the sine is periodic in 180° care must be taken that the shadowed specular region

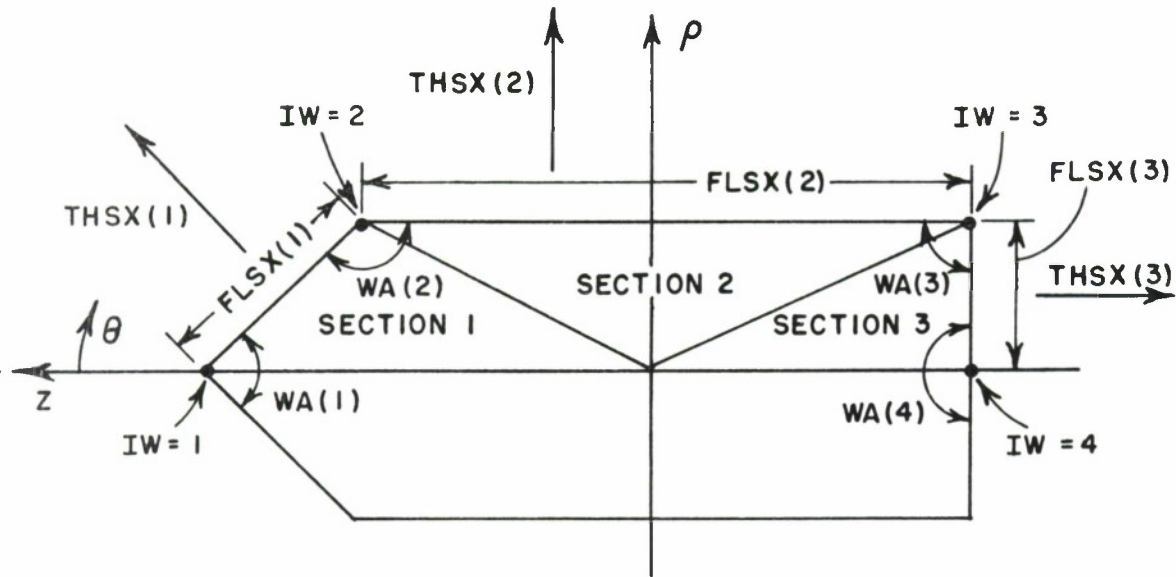


Fig. 2. A three section target-the cone-cylinder-disk.

is not included in evaluating the scattered field. This is accomplished by setting the specular angles 0° and 180° equal to 360° . These specular directions on the axis may then be evaluated using the solution for the axial caustic given in Ref. 1, and located at (0242 - 0266) in this program.

The statements (0111 - 0115) convert the computed wedge angles $WA(IWD)$ to the parameter $FN(IWD)$ required for the wedge diffraction coefficient, where IWD is the number of the particular wedge.

Having identified the required geometrical properties of the target the scattered field must now be computed. Thus the iteration for the incidence angle THT is set up (0116 - 0117) and the DO loop entered (0118). The incidence angle is incremented and the propagation vector of the incident wave is computed (0119 - 0124). Next, the total field is initialized. Then a DO loop is entered (0128) in which the total scattered field is to be obtained by summation of the individual contributions. First the location of the wedge ID is computed (0129 - 0135). Next the test parameter $BESAR$ for the axial solution region is computed. At this point a transfer to the solution for a tip scattered field is made if $ID = NWD$ (0137). A determination is now made whether the points on the

wedge ID at $\phi = 0^\circ, 180^\circ$ are illuminated or shadowed by calling the subroutine WILLY (0138 - 0143). The COMMON block is now reset (0144), having been used in the previous test, and the angle between the incident ray and the "side" of the wedge ID is computed (0145 - 0177). The phase of the backscattered field of the $\phi = 0^\circ, 180^\circ$ points on the wedge ID is calculated by the subroutine PHASE. Having completed these calculations we now move to the computation of the scattered field due to the "wedge" ID.

The first step in the field calculation is a test (0185 - 0189) to determine if the incident angle THT is in a region for which the axial solution¹ must be used. This region is bounded by the angle corresponding to the first null of the first order Bessel function $J_1(2ka \sin \theta)$. If so a transfer is made to the axial solution. Next (0190 - 0197) a test is made to determine whether the incidence angle is within a region about a specular direction specified by the first null of the $\sin(x)/x$ function. If so a transfer to the specular solution¹ is made. It is noted that as this test is made after the test for the axial region the axial solution has precedence. At this point a transfer to the solution for a tip scattered field is made if ID = 1. Locating this provision after the axial and specular region test insures that the specular region THSX(1) indicated in Fig. 2 will be included.

Having tested for regions where a special solution is required, the scattered field due to the wedge discontinuity is now computed (0201 - 0210), and added to obtain the total field. A transfer to the end of the DO loop is then made.

The solution for the specular field using the $\sin(x)/x$ formulation given in Ref. 2, is computed in 0211 - 0238. Again this field is added to obtain the total field, and upon completion transfers to the end of the DO loop.

The solution for the axially scattered fields given in Ref. 2 is computed in 0239 - 0272. Again this contribution is added to obtain the total field, and a transfer is made to the end of the DO loop.

The tip scattered fields are computed in 0273 - 0297 using the physical optics solution for the field scattered by an infinite conducting cone.⁴ Again this contribution is added to obtain the total scattered field.

Statement 301 (0297) is the end of the range of the DO loop over the number of wedges. Thus at this point the contribution of the wedge (ID) to the total field has been computed and added to the scattered field.

At the termination of the DO loop the total backscattered field EDTOT due to all contributions has been computed. Next the backscattered field and the echo area for the incident angle THT are written (0298 - 0305). After the loop on incidence angle is completed the program is terminated (0306 - 0308).

SUBROUTINES AND FUNCTIONS

Subroutine FNORM(FNVX, FNVY, FNVZ, R, THT, PHI) 0309 - 0331

This subroutine computes the normal vector (FNVX, FNVY, FNVZ) to the surface for the section whose description is in the unlabelled COMMON region. The spherical coordinates of the point at which the normal is computed are R, THT and PHI.

Subroutine FCOMM(I) 0332 - 0343

This subroutine shifts the constants describing the section I from the /DATA/COMMON into unlabelled COMMON.

Function RAD(THT) 0344 - 0363

This function calculates the distance from the origin to the surface at the angle THT. The constants describing the surface are stored in unlabelled COMMON.

Subroutine WILLY(FWI, THTI, PHI, THIN, PHIN)

This subroutine determines whether the incident wave specified by THIN, PHIN = 0., π illuminates the wedge at location THTI, PHI. If the wedge is illuminated FWI is set equal to 1., if shadowed FWI is set equal to zero.

Subroutine CROSS(X, Y, Z, A1, A2, A3, B1, B2, B3) 0384 - 0390

This subroutine computes the cross product $\overline{A} \times \overline{B}$ and returns the answer in (X, Y, Z).

Function PHASE(THTI, PHII, THTB, PHIB, RB, FK)
0391 - 0400

This function calculates the phase of the backscattered field for an incident (and scattering) direction given by THTI, PHII = 0., π , for the wedge location RB, THTB, PHIB = 0., π , with a propagation constant FK.

Function SINXX(Y) 0401 - 0408

This function computes $\sin(y)/y$.

Function DIFF1(FN, PHI, FK, BETA) 0409 - 0439

This function calculates the plane wave diffraction coefficient given in Refs. 1 and 2. FN is the wedge parameter, PHI the angular argument, FK the propagation constant, and BETA the half angle of the diffraction cone.

Function BESL0(X) 0440 - 0465

This function computes the zero order Bessel function $J_0(x)$.

Function BESL1(X) 0466 - 0491

This function computes the first order Bessel function $J_1(x)$.

Function BESL2(X) 0492 - 0501

This function computes the second order Bessel function $J_2(x)$.

INPUT DATA

A typical set of data cards is shown in Appendix II. The order of the cards is as follows:

Card #1 This card specifies in format (I15) the number of cases to be run.

Card #2 This card specifies the number of sections of the target, in format (1I5).

Card #3 This card specifies, in order, the wavelength of the incident radiation, the starting incidence angle, the final incidence angle, the increment in angle, and the polarization factor. The wavelength is in meters, the angles in degrees, and the polarization factor is (+1.) for E_θ polarization or (-1.) for E_ϕ polarization. The format is (5F10.5).

Next N cards (N=number of target sections). These cards specify in order, the initial and final angular boundaries of the section (in radians), and the constants $A_1 \dots A_6$. The format is (8F10.5).

If the number on card number 1 is different from 1, the cards #2 to (#3+N) are repeated. This is necessary if any of the following options are desired.

1. A change in incidence angle range.
2. A change in wavelength.
3. A change in polarization.
4. A change in target.

It is also possible to re-write the control statements in the program to provide more versatility in the control, that is, to provide for automatic looping over wavelength, or polarization. The form presented here is convenient as most experimental data is taken in the form of an echo area pattern, rather than as echo area versus frequency. A flow diagram of the program is given in Appendix IV.

CONCLUSIONS

This report is not intended to completely specify each detail of the computer program. It is intended to provide information about the program which is necessary to the use or modification of the program. The accuracy of the program has been tested for the case of E_θ (parallel) polarization as reported in Ref. 1. Tests for E_ϕ (perpendicular) polarization have not been completed, but some results are given in Appendix III.

APPENDIX I
COMPUTER PROGRAM

\$EXECUTE	I8J08	0000
\$I8J08	GO,MAP	0001
\$I8FTC	WEDGD LIST,NODECK	0002
	COMPLEX EDTOT,PHASE,PHWU,PHWL,WDU,WDL,EDU,EDL,ESX,EBESS,ETIP	0003
	COMPLEX DIFFI,WBS,PBESS	0004
	COMPLEX WBSP,WBSM	0005
	COMMON RAI,RA3,R81,RA9,RA10,RA11/ DATA/ARI(20),AR3(20),BR1(20),AR9(0006
	C20), AR10(20),ARI1(20)	0007
	DIMENSION THSX(20),FLSX(20),THT1(20),THTF(20)	0008
	DIMENSION VNX(20),VNY(20),VNZ(20)	0009
	DIMENSION WA(21),FN(21)	0010
1	FORMAT(115)	0011
2	FORMAT(5F10.5)	0012
3	FORMAT(8F10.5)	0013
4	FORMAT(3F15.8)	0014
5	FORMAT(5H RW1=F15.8,5H RW2=F15.8)	0015
6	FORMAT(6H FLSX=F15.8,6H THSX=F15.8)	0016
7	FORMAT(5H WDU=2F15.8,5H WDL=2F15.8,5H RDF=F15.8)	0017
8	FORMAT(4F15.8)	0018
9	FORMAT(1F15.8)	0019
10	FORMAT(6F15.8)	0020
11	FORMAT(6H THTD=F15.8,5H ESX=2F15.8)	0021
12	FORMAT(6H THTD=F15.8,7H EBESS=2F15.8)	0022
13	FORMAT(6H STTI=F15.8)	0023
14	FORMAT(6H ARSX=F15.8)	0024
15	FORMAT(6H PSIU=F15.8,6H PSIL=F15.8)	0025
16	FORMAT(6H FWIU=F15.8,6H FWIL=F15.8)	0026
17	FORMAT(6H THTW=F15.8,4H RW=F15.8,4H AW=F15.8,4H ZW=F15.8)	0027
18	FORMAT(27H PERPENDICULAR POLARIZATION)	0028
19	FORMAT(22H PARALLEL POLARIZATION)	0029
	READ(5,1) NCS	0030
	DO 600 NCSI=1,NCS,1	0031
	READ(5,1)N	0032
	READ(5,2)WAVE,THTS,THTE,DTHT,POL	0033
	WRITE(6,2)WAVE,THTS,THTE,DTHT,POL	0034
	IF(POL,LT,0.) WRITE(6,18)	0035
	IF(POL,GT,0.) WRITE(6,19)	0036
	READ(5,3)(THT1(IRD),THTF(IRD),AR1(IRD),AR3(IRD),BR1(IRD),AR9(IRD),	0037
	CAR10(IRD),AR11(IRD),IRD=1,N)	0038
	WRITE(6,3)(THT1(J),THTF(J),AR1(J),AR3(J),BR1(J),AR9(J),AR10(J),AR1	0039
	C1(J),J=1,N)	0040
	PI=3.1415927	0041
	TP=2.*PI	0042
	PI2=PI/2.	0043
	FK=TP/WAVE	0044
	DEGRAD=0.01745329	0045
C	WEDGE DETERMINATION	0046
C	NUMBER OF TARGET SECTIONS=N	0047
C	CLOSED TARGET ASSUMED	0048
	NWD=N+1	0049
	DLARGE=0.	0050
	DIA=0.	0051
	TCT=0.90	0052
	DO 201 IW=1,N,1	0053
	THSX(IW)=TP	0054
	FLSX(IW)=0.	0055
	THT1=THT1(IW)	0056
	THT2=THTF(IW)	0057
	CALL FCOMM(IW)	0058
	RW1=RAD(THT1)	0059
	RW2=RAD(THT2)	0060
	CALL FNORM(FX1,FY1,FZ1,RW1,THT1,0.)	0061
	CALL FNORM(FX2,FY2,FZ2,RW2,THT2,0.)	0062
	IF(IW,EQ,1) GO TO 202	0063

	IW1=IW-1	0064
	THT3=THTF(IW1)	0065
	CALL FCOMM(IW1)	0066
	RW3=RAD(THT3)	0067
	CALL FNORM(FX3,FY3,FZ3,RW3,THT3,0.)	0068
	SPRD=FX1*FX3+FY1*FY3+FZ1*FZ3	0069
	VNX(IW)=FX3	0070
	VNY(IW)=FY3	0071
	VNZ(IW)=FZ3	0072
	DANG=ARCOS(ABS(SPRD))	0073
	IF(SPRD.LT.0.) DANG=PI-DANG	0074
	WA(IW)=PI-DANG	0075
	IF(IW.EQ.N)GO TO 203	0076
207	CONTINUE	0077
C	CHECK FOR SIN(X)/X REGION	0078
	SPX=FX1*FX2+FY1*FY2+FZ1*FZ2	0079
	SPX=ABS(SPX)	0080
	IF (SPX.GT.TCT)GO TO 204	0081
	GO TO 500	0082
202	CONTINUE	0083
C	CHECK FOR WEDGE ANGLE ON THE END	0084
	VNX(1)=FX1	0085
	VNY(1)=FY1	0086
	VNZ(1)=FZ1	0087
	WA(1)=PI-2.*ATAN2(FX1,FZ1)	0088
	GO TO 207	0089
203	CONTINUE	0090
C	CHECK FOR WEDGE ANGLE ON THE END	0091
	FZ2A=ABS(FZ2)	0092
	VNX(NWD)=FX2	0093
	VNY(NWD)=FY2	0094
	VNZ(NWD)=FZ2	0095
	WA(NWD)=PI-2.*ATAN2(FX2,FZ2A)	0096
	GO TO 207	0097
204	CONTINUE	0098
	THSX(IW)=ATAN2(FX1,FZ1)	0099
	THHX=THSX(IW)	0100
	IF(IW.GT.1 .AND. ABS(THHX).EQ.0.) THSX(IW)=PI	0101
	FLSX(IW)=SQRT(ABS(RW1*RW1+RW2*RW2-2.*RW1*RW2*COS(THT2-THT1)))	0102
	GLSX=FLSX(IW)	0103
	WRITE(6,5) RW1,RW2	0104
	WRITE(6,5) THT1,THT2	0105
	WRITE(6,6) GLSX,THHX	0106
500	CONTINUE	0107
201	CONTINUE	0108
	IF(THSX(1).LT.0.1) THSX(1)=TP	0109
	IF(ABS(THSX(N)-PI).LT.0.1) THSX(N)=TP	0110
	DO 208 IWD=1,NWD,1	0111
	FN(IWD)=(TP-WA(IWD))/PI	0112
	FNWR=FN(IWD)	0113
	WRITE(6,9)FNWR	0114
208	CONTINUE	0115
	FLOOP=ABS((THTS-THTE)/DTHT)	0116
	LOOP=FLOOP+1.	0117
	DO 400 LP=1,LOOP,1	0118
	FLP=LP	0119
	THTD=(FLP-1.)*DTHT	0120
	THT=DEGRAD*THTD	0121
	VX=-SIN(THT)	0122
	VY=0.	0123
	VZ=-COS(THT)	0124
C	PARALLEL POLARIZATION	0125
	EDTOT=(0.,0.)	0126
	IDSX=0	0127

	DO 301 ID=1,NWD,1	0128
	THTW=THT1(ID)	0129
	CALL FCOMM(ID)	0130
	IF(ID.EQ.NWD) THTW=THTF(N)	0131
	RW=RAD(THTW)	0132
	AW=RW*SIN(THTW)	0133
	ZW=RW*COS(THTW)	0134
	WRITE(6,17) THTW,RW,AW,ZW	0135
	BESAR=2.*FK*AW	0136
	IF(ID.EQ.NWD) GO TO 305	0137
	IF(THT.LT.PI2.AND.ID.GT.1) CALL FCOMM(ID-1)	0138
	CALL WILLY(FW1,THTW,0.,THT,0.)	0139
	FW1U=FW1	0140
	CALL WILLY(FW1,THTW,P1,THT,0.)	0141
	FW1L=FW1	0142
	WRITE(6,16) FW1U,FW1L	0143
	CALL FCOMM(ID)	0144
306	CONTINUE	0145
C	FIND INCIDENCE ANGLE ON WEDGE	0146
C	INCIDENCE VECTOR VX,VY,VZ	0147
	VXM=-VX	0148
	VYM=-VY	0149
	VZM=-VZ	0150
	IF(THT.GT.PI2) GO TO 309	0151
	SPRD=VXM*VN1(ID)+VZM*VN2(ID)	0152
	CALL CROSS(BX,BY,BZ,VXM,VYM,VZM,VN1(ID),VN2(ID),VN3(ID))	0153
	DANG=ARCOS(SPRD)	0154
	SIGN=-1.	0155
	IF(BY.LT.0.) SIGN=1.	0156
	PSIU=P12+SIGN*DANG	0157
	SPRD=-VXM*VN1(ID)+VZM*VN2(ID)	0158
	CALL CROSS(BX,BY,BZ,VXM,VYM,VZM,-VN1(ID),VN2(ID),VN3(ID))	0159
	DANG=ARCOS(SPRD)	0160
	SIGN=1.	0161
	IF(BY.LT.0.) SIGN=-1.	0162
	PSIL=P12+SIGN*DANG	0163
	GO TO 310	0164
309	CONTINUE	0165
	CALL FNORM(FTX,FTY,FTZ,RW,THT,0.)	0166
	SPRD=VXM*FTX+VYM*FTY+VZM*FTZ	0167
	CALL CROSS(BX,BY,BZ,VXM,VYM,VZM,FTX,FTY,FTZ)	0168
	DANG=ARCOS(SPRD)	0169
	SIGN=1.	0170
	IF(BY.LT.0.) SIGN=-1.	0171
	PSIU=P12+SIGN*DANG	0172
	SPRD=-VXM*FTX+VYM*FTY+VZM*FTZ	0173
	DANG=ARCOS(SPRD)	0174
	PSIL=P12-DANG	0175
310	CONTINUE	0176
	WRITE(6,15)PSIU,PSIL	0177
C	DETERMINE PHASE OF WEDGE	0178
	PHWU=PHASE(THT,0.,THTW,0.,RW,FK)	0179
	PHWL=PHASE(THT,0.,THTW,P1,RW,FK)	0180
	PSUP=2.*PSIU	0181
	PSUM=0.	0182
	PSLP=2.*PSIL	0183
	PSLM=0.	0184
C	BESSLO TEST	0185
	STTD=3.8317/BESAR	0186
	STTI=SIN(THT)	0187
	WRITE(6,13) STTI	0188
	IF(STTI.LT.STTD)GO TO 302	0189
C	SIN(X)/X TEST	0190
	IDX=ID	0191

	T1=ABS(THSX(1DX)-THT)	0192
	IF(T1.GT.P12) T1=P12	0193
	ARSX=2.*FK*FLSX(1DX)*SIN(T1)	0194
	WRITE(6,14)ARSX	0195
	IF(ARSX.LT.P1)GOTO 304	0196
303	CONTINUE	0197
	NCHECK=303	0198
	WRITE(6,1) NCHECK	0199
	IF(1D.E0.1) GO TO 305	0200
C	CALCULATE DIFFRACTED FIELDS	0201
	WDU=DIFF1(FN(1D),PSUP,FK,P12)+POL*DIFF1(FN(1D),PSUM,FK,P12)	0202
	IF(1D.E0.1DSX) WDU=(0.,0.)	0203
	WDL=DIFF1(FN(1D),PSLP,FK,P12)+POL*DIFF1(FN(1D),PSLM,FK,P12)	0204
	RDF=SQRT(ABS(AW/(2.*SIN(THT))))	0205
	WRITE(6,7) WDU,WDL,RDF	0206
	EDU=RDF*PHWU*WDU*FW1U	0207
	EDL=RDF*PHWL*WDL*FW1L	0208
	EDTOT=EDTOT+EDU+EDL	0209
	GO TO 301	0210
304	CONTINUE	0211
	NCHECK=304	0212
	WRITE(6,1) NCHECK	0213
C	COMPUTE SIN(X)/X CONTRIBUTION	0214
C	COMPUTE PEAK RETURN USING AVERAGE OF GAUSSIAN CURVATURE	0215
	RW1=RW	0216
	RW2=RAD(THTF(1D))	0217
	AW1=AW	0218
	AW2=RW2*SIN(THTF(1D))	0219
	TAW=ABS(AW1-AW2)	0220
	IF(TAW.LT.0.1) GO TO 307	0221
	RH1=AW1/SIN(THT)	0222
	RH2=AW2/SIN(THT)	0223
	RH1=ABS(RH1)	0224
	RH2=ABS(RH2)	0225
	RSH1=SQRT(RH1)	0226
	RSH2=SQRT(RH2)	0227
	PEAK=ABS(RSH1*RH1-RSH2*RH2)*FLSX(1D)*1.414/(3.*ABS(RH1-RH2))	0228
	PEAK=FK*PEAK	0229
	GO TO 308	0230
307	PEAK=SQRT(AW1/2.)*FK*FLSX(1D)	0231
308	CONTINUE	0232
	ESX=-PEAK*SINXX(ARSX)/SQRT(TP*FK)	0233
	ESX=ESX*PHASE(THT,0.,THTW,0.,RW,FK)	0234
	1DSX=1D+1	0235
	WRITE(6,11)THTD,ESX	0236
	EDTOT=EDTOT+ESX	0237
	GO TO 301	0238
302	CONTINUE	0239
	NCHECK=302	0240
	WRITE(6,1) NCHECK	0241
C	COMPUTE FIELD USING BESSEL FUNCTIONS	0242
	SBSS=0.5	0243
	PKSPC=FK*AW*AW	0244
	PKBSS=AW	0245
	ARGBS=BESAR*SIN(THT)	0246
	IF(ABS(ARGBS).GT.0.05) SBSS=BESL1(ARGBS)/ARGBS	0247
	CALL FNORM(F1X,F1Y,F1Z,RW,THTW,0.)	0248
	PSUB=2.*(P12-ARCOS(ABS(F1Z)))	0249
	IF(THT.LT.P12) PSUB=2.*(P12-ARCOS(VNZ(1D)))	0250
	WBS=DIFF1(FN(1D),PSUB,FK,P12)	0251
	PBESS=PHASE(THT,0.,0.,0.,ZW,FK)	0252
	SHBDT=CABS(WBS)-0.5	0253
	IF(ABS(SHBDT).LT.0.05) GO TO 321	0254
	WBS=WBS*SQRT(TP*FK)	0255

	COST=COS(THT)	0256
	WBSP=DIFF1(FN(ID),0.,FK,P12)+DIFF1(FN(ID),PSUB,FK,P12)	0257
	WBSM=DIFF1(FN(ID),0.,FK,P12)-DIFF1(FN(ID),PSUB,FK,P12)	0258
	WBSP=WBSP*SQRT(FK*TP)	0259
	WBSM=WBSM*SQRT(TP*FK)	0260
	WBS=-COST*COST*WBSM*SBSS+WBSP*(SBSS-BESL2(ARGBS))	0261
	IF(POL.LT.0.) WBS=COST*COST*WBSP*SBSS-WBSM*(SBSS-BESL2(ARGBS))	0262
	EBESS=(0.,-1.)*PKBSS*PBESS*WBS	0263
	IF(FWIU.EQ.0..AND.FWIL.EQ.0.) EBESS=(0.,0.)	0264
	IF(FWIU.GT.0..AND.FWIL.EQ.0.) EBESS=0.5*EBESS	0265
	GO TO 322	0266
321	CONTINUE	0267
	EBESS=(0.,-1.)*PKSPC*PBESS*SBSS	0268
322	CONTINUE	0269
	WRITE(6,12) THTD,EBESS	0270
	EDTOT=EDTOT+EBESS	0271
	GO TO 301	0272
305	CONTINUE	0273
	NCHECK=305	0274
	WRITE(6,1) NCHECK	0275
C	COMPUTE TIP CONTRIBUTION AT ENDS	0276
C	TO FIRST ORDER TIP CONTRIBUTIONS ARE NEGLEGIBLE	0277
	THTCN=THT	0278
	IF(THT.GT.P12) THTCN=P1-THT	0279
	HFCA=0.5*WA(ID)	0280
	TCNA=P12-HFCA	0281
	TCNAA=ABS(THTCN-TCNA)	0282
	IF(TCNAA.LT.0.1745) GO TO 312	0283
	IF(ABS(HFCA-P12).LT.0.1745) GO TO 312	0284
	TANA=TAN(HFCA)	0285
	TANA2=TANA*TANA	0286
	TANTH=TAN(THTCN)	0287
	TANT2=TANTH*TANTH	0288
	COSTH=COS(THTCN)	0289
	COSTH3=COSTH*COSTH*COSTH	0290
	ETIP=-WAVE*TANA2/(8.*PI*COSTH3*(1.-TANA2*TANT2))	0291
	ETIP=ETIP*PHASE(THT,0.,0.,0.,ZW,FK)	0292
	IF(POL.LT.0.) ETIP=-ETIP	0293
	GO TO 311	0294
312	ETIP=(0.,0.)	0295
311	CONTINUE	0296
	EDTOT=EDTOT+ETIP	0297
301	CONTINUE	0298
C	OUTPUT SECTION	0299
	WRITE(6,4) THTD,EDTOT	0300
	EMAG=CABS(EDTOT)	0301
	SIGMA=2.*TP*EMAG*EMAG/(WAVE*WAVE)	0302
	SIGMAL=10.*ALOG10(SIGMA)	0303
	WRITE(6,4)SIGMA,SIGMAL	0304
400	CONTINUE	0305
600	CONTINUE	0306
	STOP	0307
	END	0308
\$IBFTC	FFNRM LIST,NODECK	0309
	SUBROUTINE FNORM(FNVX,FNVY,FNVZ,R,THT,PHI)	0310
C	INPUT R,THT,PHI	0311
	COMMON AR1,AR3,BR1,AR9,AR10,AR11	0312
	ST=SIN(THT)	0313
	CT=COS(THT)	0314
	SP=SIN(PHI)	0315
	CP=COS(PHI)	0316
	U=AR1*ST*ST+AR3*CT*CT+BR1*ST*CT	0317
	V=AR9*CT+AR10*ST	0318
	UTH=2.*(AR1-AR3)*ST*CT+BR1*(CT*CT-ST*ST)	0319

VTH=-AR9*ST+AR10*CT	0320
F1=2.*R*U+V	0321
F2=R*UTH+VTH	0322
FX=ST*CP*F1+CT*CP*F2	0323
FY=ST*SP*F1+CT*SP*F2	0324
FZ=CT*F1-ST*F2	0325
FN=SQRT(FX*FX+FY*FY+FZ*FZ)	0326
FNXX=FX/FN	0327
FNYY=FY/FN	0328
FNZZ=FZ/FN	0329
RETURN	0330
END	0331
\$IBFTC FCOMM. LIST,NODECK	0332
SUBROUTINE FCOMM(I)	0333
COMMON RA1,RA3,RB1,RA9,RA10,RA11/ DATA/AR1(20),AR3(20),BR1(20),AR9(0334
C20),AR10(20),AR11(20)	0335
RA1=AR1(I)	0336
RA3=AR3(I)	0337
RB1=BR1(I)	0338
RA9=AR9(I)	0339
RA10=AR10(I)	0340
RA11=AR11(I)	0341
RETURN	0342
END	0343
\$IBFTC RADD LIST,NODECK	0344
FUNCTION RAD(THT)	0345
C CALCULATE R	0346
COMMON AR1,AR3,BR1,AR9,AR10,AR11	0347
R=0.	0348
ST=SIN(THT)	0349
CT=COS(THT)	0350
C1=AR1*ST*ST+AR3*CT*CT+BR1*ST*CT	0351
C2=AR9*CT+AR10*ST	0352
C3=AR11	0353
IF(C1.EQ.0.)GO TO 11	0354
ARG=SQRT(C2*C2-4.*C1*C3)	0355
R=(-C2+ARG)/(2.*C1)	0356
R2=(-C2-ARG)/(2.*C1)	0357
IF(R2.LT.R.AND.R2.GT.0.) R=R2	0358
GO TO 12	0359
11 R=-C3/C2	0360
12 RAD=ABS(R)	0361
RETURN	0362
END	0363
\$IBFTC WILLY. LIST,NODECK	0364
SUBROUTINE WILLY(FWI,THT1,PHI,THIN,PHIN)	0365
C INPUT THT1,PHI,THIN,PHIN	0366
C FWI=0. WEDGE IN SHADOW	0367
C FWI=1. WEDGE ILLUMINATED	0368
COMMON AR1,AR3,BR1,AR9,AR10,AR11	0369
PI=3.1415927	0370
PI2=1.5707963	0371
R=RAD(THT1)	0372
CALL FNORM(FNX,FNY,FNZ,R,THT1,PHI)	0373
TH=THIN	0374
XIN=SIN(TH)*COS(PHIN)	0375
YIN=0.	0376
ZIN=COS(TH)	0377
SPRD=FNX*XIN+FNY*YIN+FNZ*ZIN	0378
FWI=1.	0379
IF(SPRD.LT.0.) FWI=0.	0380
CONTINUE	0381
RETURN	0382
END	0383

\$IBFTC CROSS. LIST,NODECK	0384
SUBROUTINE CROSS(X,Y,Z,A1,A2,A3,B1,B2,B3)	0385
X=A2*B3-A3*B2	0386
Y=A3*B1-A1*B3	0387
Z=A1*B2-A2*B1	0388
RETURN	0389
END	0390
\$IBFTC PHAS. LIST,NODECK	0391
COMPLEX FUNCTION PHASE(THTI,PHII,THTB,PHIB,RB,FK)	0392
FS=1.	0393
TEST=ABS(PHII-PHIB)	0394
IF(TEST.EQ.0.) FS=-1.	0395
FL=2.*RB*COS(THTI+FS*THTB)	0396
FKL=FK*FL	0397
PHASE=CMPLX(COS(FKL),SIN(FKL))	0398
RETURN	0399
END	0400
\$IBFTC SINXX. LIST,NODECK	0401
FUNCTIONSINXX(Y)	0402
C SIN(X)/X FUNCTION	0403
Z=Y*Y	0404
SINXX=(1.-(Z/6.)*(1.-(Z/20.)*(1.-(Z/42.)*(1.-(Z/72.)*(1.-(Z/110.)*	0405
2(1.-(Z/156.)*(1.-(Z/182.))))))	0406
RETURN	0407
END	0408
\$IBFTC DIFCN LIST,NODECK	0409
COMPLEX FUNCTION DIFF1(FN,PHI,FK,BETA)	0410
C SINGLE DIFFRACTION FUNCTION DIFF1	0411
C FN=WEDGE ANGLE, PHI=ARGUMENT, BETA=CONC ANGLE	0412
COMPLEX EXPH	0413
PI=3.1415927	0414
TP=2.*PI	0415
PI4=PI/4.	0416
PIF=PI/FN	0417
PHN=PHI/FN	0418
PHIA=ABS(PHI)	0419
EXPH=CEXP((0.,-1.)*PI4)	0420
SINB=SIN(BETA)	0421
SINB=ABS(SINB)	0422
IF(SINB.LT..001) GO TO 3	0423
IF(ABS(PHIA-PI).LT.0.1) GO TO 1	0424
T1=COS(PIF)	0425
T2=COS(PHN)	0426
T3=SIN(PIF)	0427
T4=T1-T2	0428
T4A=ABS(T4)	0429
IF(T4A.LT..001) GO TO 3	0430
DIFF1=EXPH*T3/(FN*SINB*T4)	0431
DIFF1=DIFF1/SQRT(TP*FK)	0432
GO TO 2	0433
1 DIFF1=0.5/SINB	0434
GO TO 2	0435
3 DIFF1=1000.	0436
2 CONTINUE	0437
RETURN	0438
END	0439
\$IBFTC BESLO. LIST,NODECK	0440
FUNCTION BESLO(X)	0441
C (X.GT.0.)	0442
Z=ABS(X)	0443
Y=X/3.	0444
Y2=Y*Y	0445
Y3=Y2*Y	0446
Y4=Y2*Y2	0447

	Y5=Y3*Y2	0448
	Y6=Y4*Y2	0449
	Y8=Y6*Y2	0450
	Y10=Y8*Y2	0451
	Y12=Y10*Y2	0452
	IF(Z.GT.3.)GO TO 10	0453
	BESL0=1.-2.2499997*Y2+1.2656208*Y4-.3163866*Y6+.0444479*Y8-.003944	0454
	24*Y10-.00024846*Y12	0455
	GO TO 11	0456
10	CONTINUE	0457
	F=.79788456-(.00000077/Y)-(.00552740/Y3)-(.00009512/Y3)+(.00137237	0458
	2/Y4)-(.00072805/Y5)+(.00014476/Y6)	0459
	T=X-.78539816-(.04156397/Y)-(.00003954/Y2)+(.00262573/Y3)-(.000541	0460
	225/Y4)-(.00029333/Y5)+(.00013558/Y6)	0461
	BESL0=F*COS(T)/SQRT(X)	0462
11	CONTINUE	0463
	RETURN	0464
	END	0465
\$1BFTC	BESL1. LIST,NODECK	0466
	FUNCTION BESL1(X)	0467
C	POLYNOMIAL APPROXIMATION X.GT.0.	0468
	Y=X/3.	0469
	Y2=Y*Y	0470
	Y3=Y2*Y	0471
	Y4=Y3*Y	0472
	Y5=Y4*Y	0473
	Y6=Y5*Y	0474
	Y8=Y6*Y2	0475
	Y10=Y8*Y2	0476
	Y12=Y10*Y2	0477
	IF(X.GT.3.)GO TO 10	0478
	BESL=0.5-.56249985*Y2+.21093573*Y4-.03954289*Y6+.00443319*Y8-.0003	0479
	21761*Y10+.00001109*Y12	0480
	BESL1=X*BESL	0481
	GO TO 11	0482
10	CONTINUE	0483
	F=.79788456+(.00000156/Y)+(.01659667/Y2)+(.00017105/Y3)-(.00249511	0484
	2/Y4)+(.00113653/Y5)-(.00020033/Y6)	0485
	T=X-2.35619449+(.12499612/Y)+(.00005650/Y2)-(.00637879/Y3)+(.00074	0486
	2348/Y4)+(.00079824/Y5)-(.00029166/Y6)	0487
	BESL1=F*COS(T)/SQRT(X)	0488
11	CONTINUE	0489
	RETURN	0490
	END	0491
\$1BFTC	BESL2. LIST,NODECK	0492
	FUNCTION BESL2(X)	0493
C	(X.GT.0.)	0494
	IF(X.EQ.0.)GO TO 10	0495
	BESL2=(2.*BESL1(X)/X)-BESL0(X)	0496
	GO TO 11	0497
10	BESL2=0.	0498
11	CONTINUE	0499
	RETURN	0500
	END	0501
\$DATA		0502

APPENDIX II INPUT DATA

00002

00003

1.0	0.	180.	1.0	-1.			
0.	.785398	0.	0.	0.	2.0	1.0	-2.0
.785398	2.617	0.	0.	0.	0.	1.0	-1.0
2.617	3.1415927	0.	0.	0.	-1.0	0	-2.0

00003

1.0	0.	180.	1.0	1.0			
0.	.785398	0.	0.	0.	2.0	1.0	-2.0
.785398	2.617	0.	0.	0.	0.	1.0	-1.0
2.617	3.1415927	0.	0.	0.	-1.0	0.	-2.0

APPENDIX III

COMPUTER TESTS FOR E_ϕ POLARIZATION

A limited amount of data has been obtained for the case of E_ϕ polarization. The computed results are compared with measured data for the cone and double cone in Figs. 3 and 4. The data for the cone is that of Keys and Primich⁵ and the double cone data is from Eberle and St. Clair.⁶ For the case of the cone the greatest error is in the near forward region where the single diffraction solution is used. The results in this region agree with the single diffraction results of Bechtel.⁷ The results in this region could be improved by extending the edge current formulation for the axially scattered fields to this region. In the case of the double cone the calculated echo area is in error in the region about $\theta = 90^\circ$. This is a region where the effect of edge type creeping waves¹ at the junction should be considered. These test results indicate that further extension of the theory and computer program is necessary to remove these sources of error. However, for targets which are large in terms of wavelength the accuracy will improve, as both the edge current and creeping wave effects would diminish.

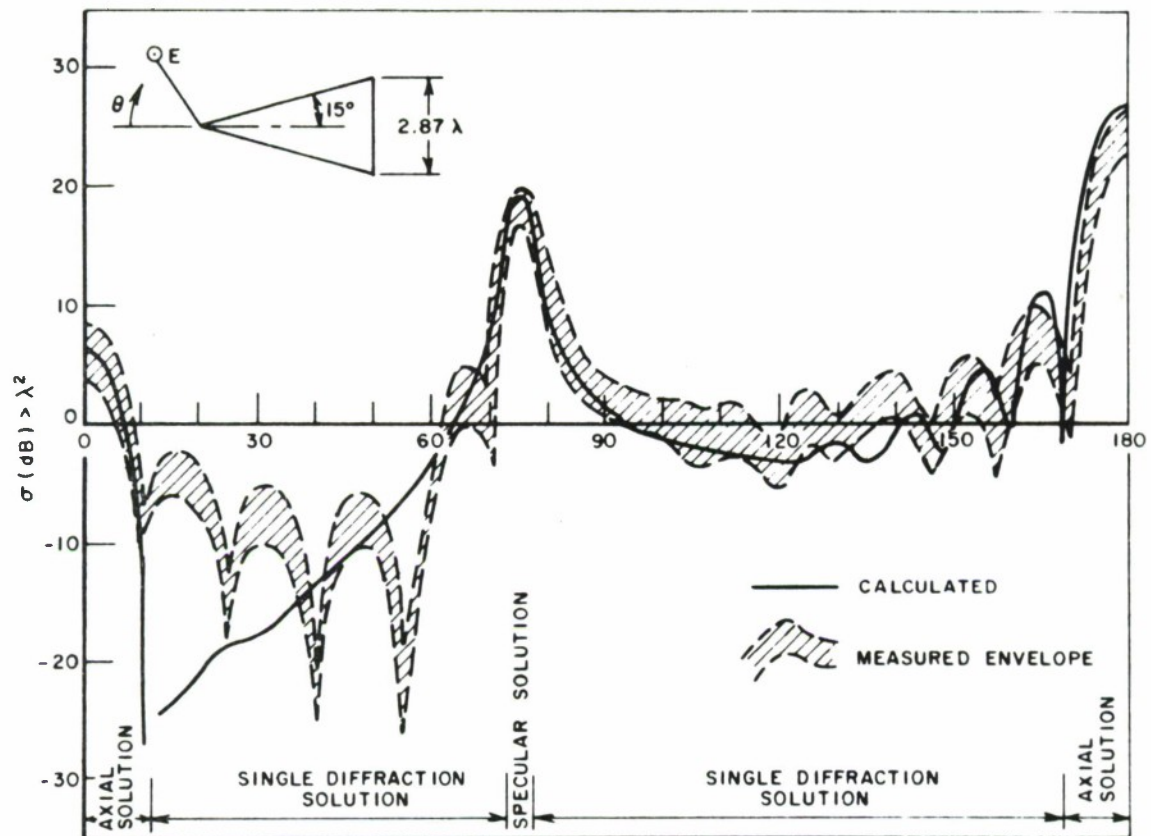


Fig. 3. Echo area of a cone- E_ϕ polarization.

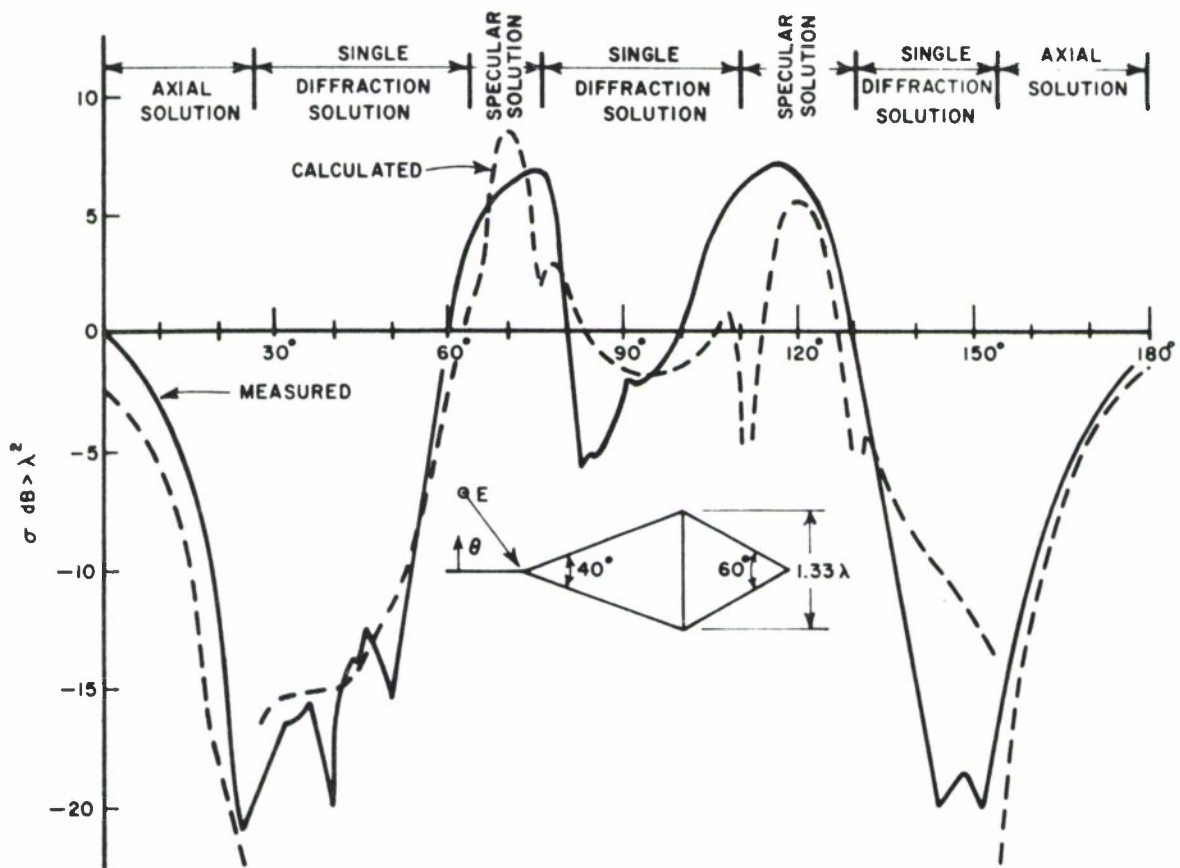
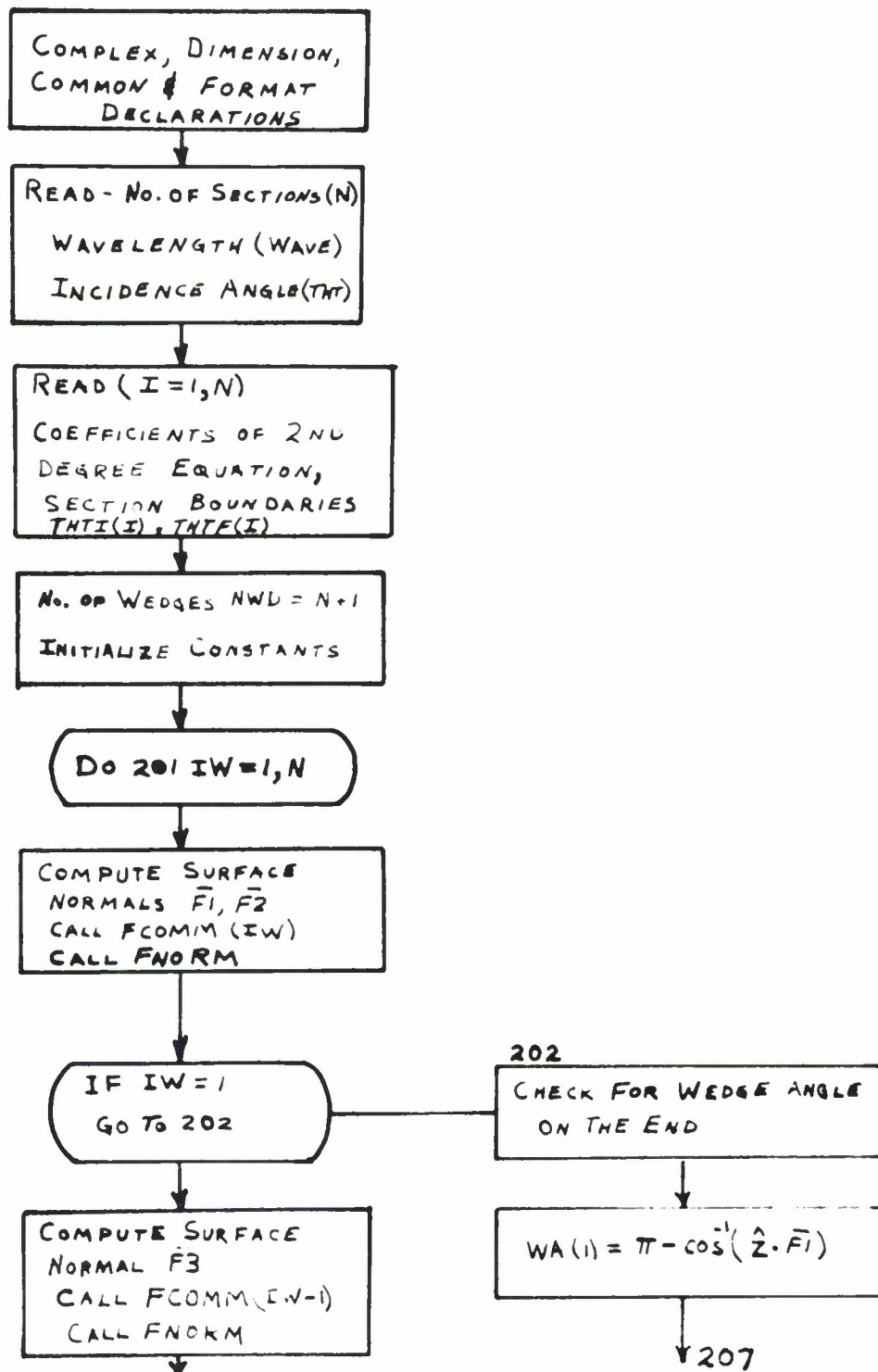


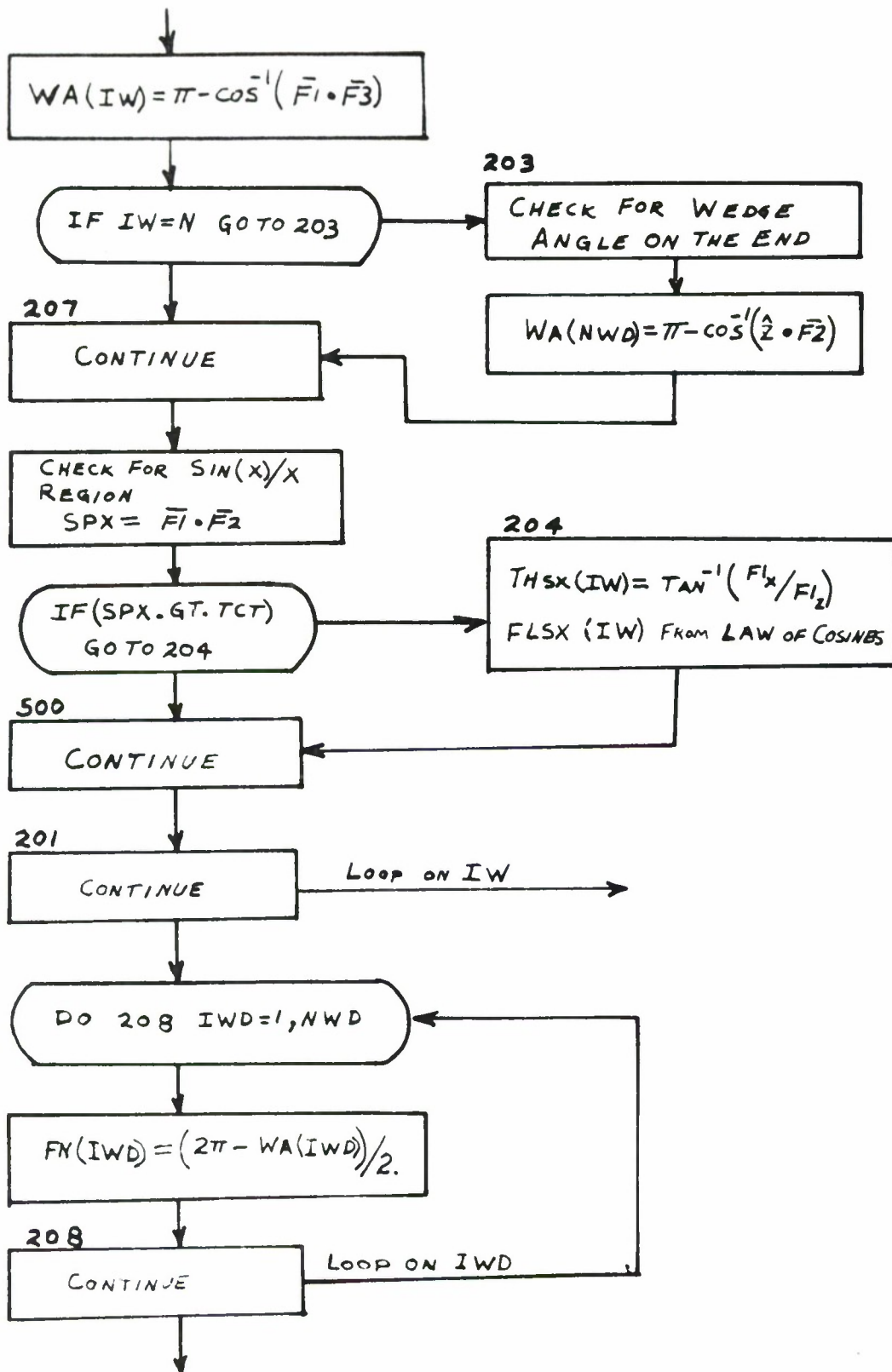
Fig. 4. Echo area of a double cone- E_ϕ polarization.

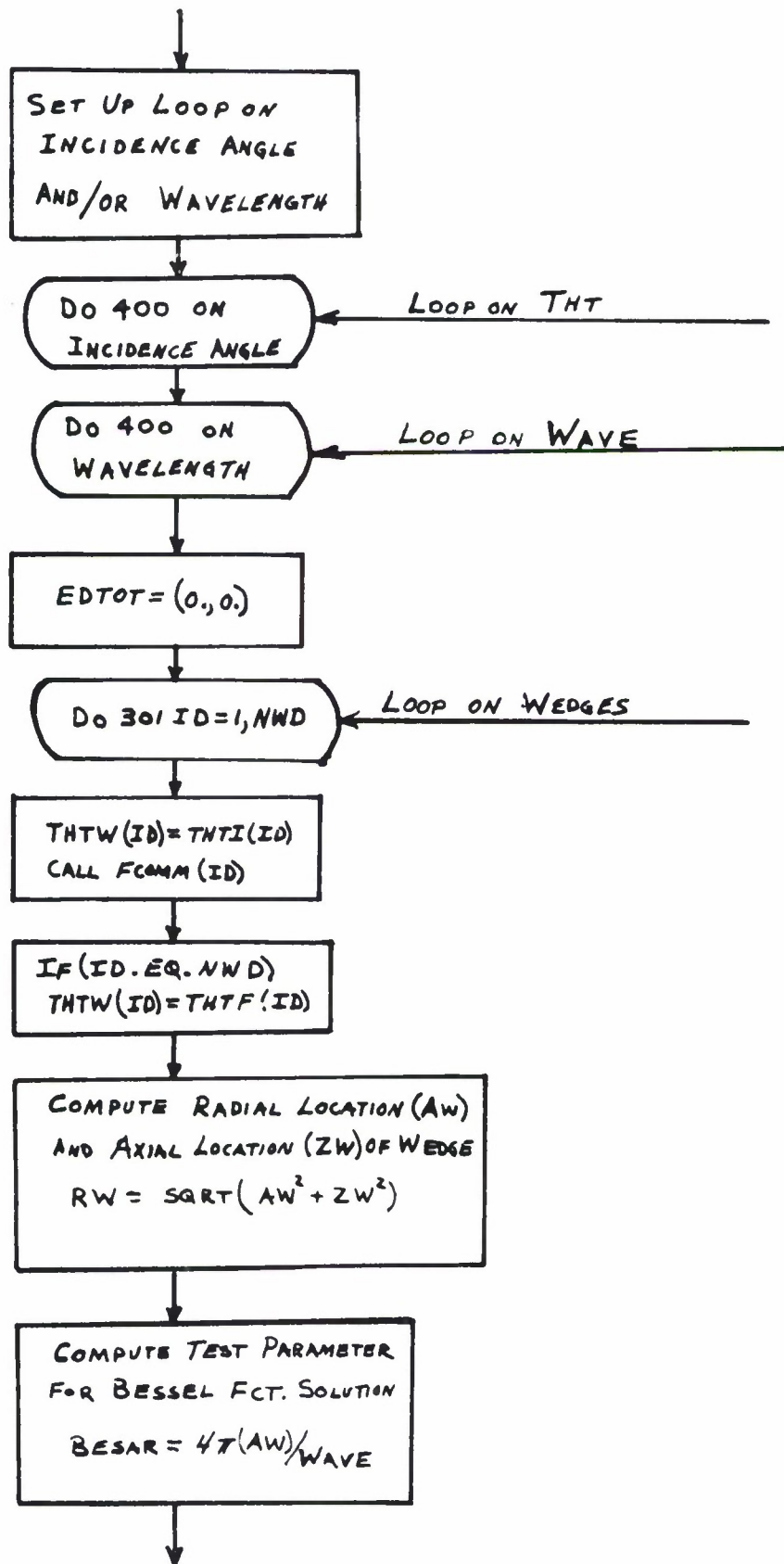
APPENDIX IV
WEDGE DIFFRACTION COMPUTER PROGRAM
FLOW DIAGRAM

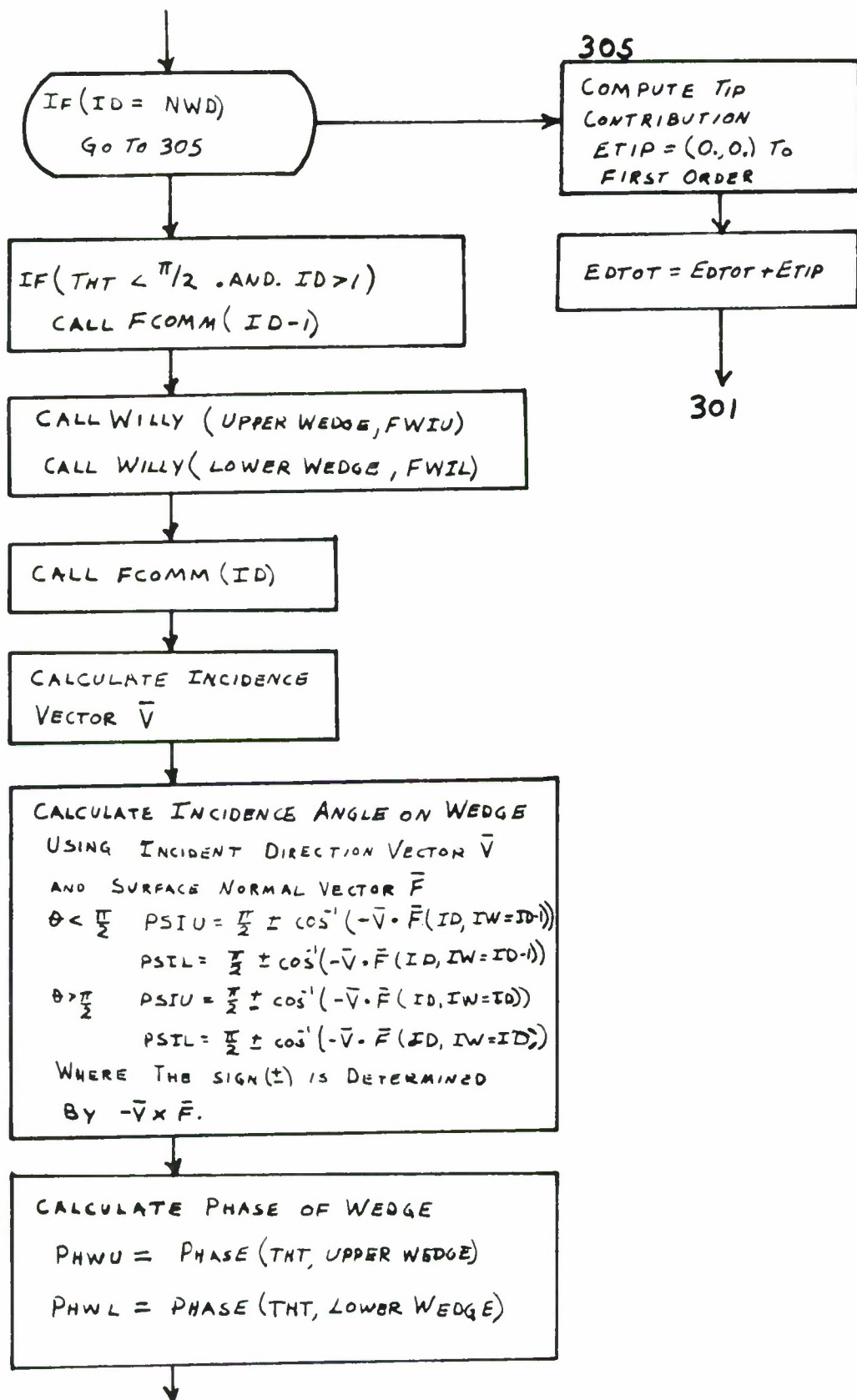
The flow diagram for the wedge diffraction Computer program WEDGD is given in Fig. 5. This flow diagram has also been presented in Ref. 1.

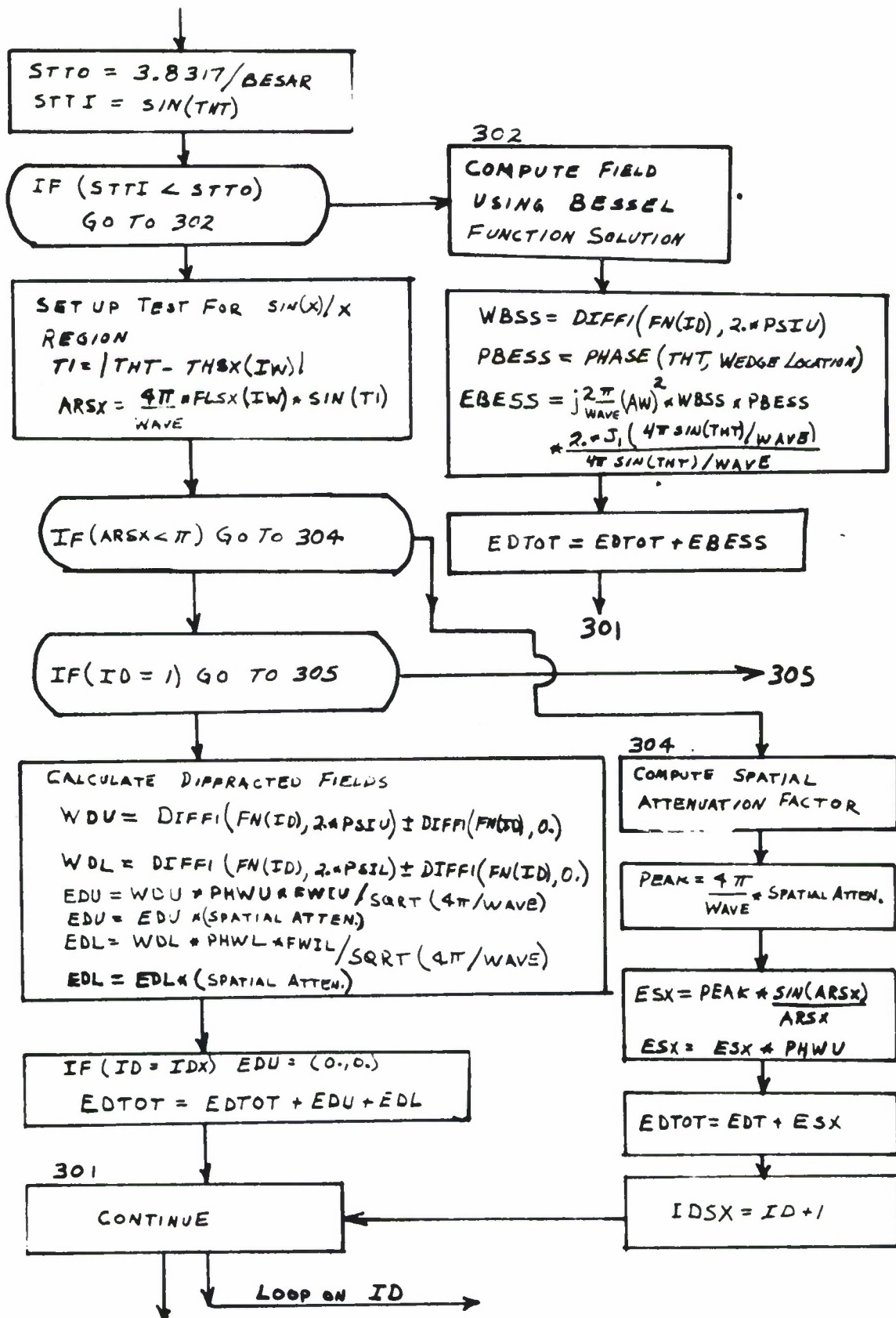
WEDGE DIFFRACTION COMPUTER PROGRAM

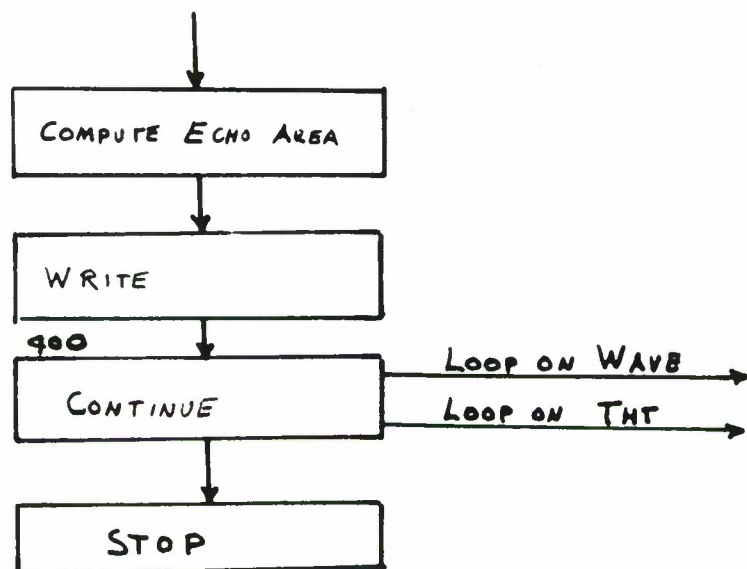












REFERENCES

1. Ryan, C.E., Jr., "A Geometrical Theory of Diffraction Analysis of the Radar Cross Section of a Sectionally Continuous Second Degree Surface of Revolution," Report 2430-4, April 1968, ElectroScience Laboratory, The Ohio State University Research Foundation; prepared under Contract F-19628-67-C-0318 for Department of the Air Force, Electronic Systems Division, L.G. Hanscom Field, Bedford, Massachusetts.
2. Ryan, C.E., Jr., "Memorandum on Analysis of Echo Area of Targets Using Geometrical Theory of Diffraction and Creeping Wave Theory," Report 2430-1, 22 May 1967, ElectroScience Laboratory, The Ohio State University Research Foundation; prepared under Contract F-19628-67-C-0318 for Department of the Air Force, Electronic Systems Division, L.G. Hanscom Field, Bedford, Massachusetts. (AD 658 469).
3. Ryan, C.E., Jr., "A Computer Program for Backscatter by Smoothly Joined, Second Degree Surfaces of Revolution," Report 2430-6. (Report in preparation).
4. Crispin, J.W., Jr., and Maffett, A.L., "Radar Cross Section Estimation for Simple Shapes," Proc. IEEE, Vol. 53, No. 8, (August 1965), p. 838.
5. Keys, J.E. and Primich, R.I., "The Radar Cross Section of Right Circular Metal Cones," Defense Research Telecommunications Establishment, Ottawa, Canada, Report 1010, May 1959. ASTIA doc. AD 217-921.
6. Bechtel, M.E., "Application of Geometric Diffraction Theory to Scattering From Cones and Disks," Proceedings of the IEEE, (August 1965), pp. 877-882.
7. Eberle, J.W. and St. Claire, R.W., "Echo Area of Combinations of Cones, Spheroids, and Hemispheres as a Function of Bistatic Angle and Target Aspect," Report 1073-1, 30 June 1960, Antenna Laboratory, The Ohio State University Research Foundation; prepared under Contract AF 19(604)-6157 for Air Force Cambridge Research Center, L.G. Hanscom Field, Bedford, Massachusetts. (AD 242-472) (AFCRC-TN-60-795).

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R&D		
<i>(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)</i>		
1. ORIGINATING ACTIVITY <i>(Corporate author)</i> ElectroScience Laboratory The Ohio State University, Department of Electrical Engineering, 1320 Kinnear Rd., Columbus, Ohio		2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP N/A
3. REPORT TITLE A Computer Program for Backscatter by Targets Composed of Cones, Cylinders, and Disks		
4. DESCRIPTIVE NOTES <i>(Type of report and inclusive dates)</i> Technical Report		
5. AUTHOR(S) <i>(Last name, first name, initial)</i> Ryan, C.E., Jr.		
6. REPORT DATE April 1968	7a. TOTAL NO. OF PAGES 31	7b. NO. OF REFS 6
8a. CONTRACT OR GRANT NO. F-19628-67-C-0308 b. PROJECT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) ESD-TR-68-212	
c. TASK d.	9b. OTHER REPORT NO(S) <i>(Any other numbers that may be assigned this report)</i>	
10. AVAILABILITY/LIMITATION NOTICES This document has been approved for public release and sale; its distribution is unlimited.		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Deputy for Surveillance and Control Systems, Electronic Systems Division L.G. Hanscom Field, Bedford, Mass.	
13. ABSTRACT <p>This report describes a computer program for determining the back-scattered fields of a conducting body of revolution composed of sections of cones and cylinders. The target may be closed at one or both ends with circular disks. The target may have as many as 20 sections, and the program can readily be modified to handle a larger number. The back-scattered field for E_0 or E_ϕ polarization is computed using wedge diffraction theory and geometrical optics. The computed results are in good agreement with experimental measurements for cones, cylinders, double cones, and conically capped cylinders.</p>		

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Radar cross section Backscatter Surface of revolution Combination of cones, frustums, and disks Geometrical optics Diffraction theory						

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